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Accretionoof fuel in Lodgepole Pine

Forests of Southwest Montana

FINAL REPORT

THE ACCRETION OF FUEL IN LODGEPOLE PINE FORESTS OF SOUTHWEST MONTANA.

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TABLE OF CONTENTS

	Page
Introduction	1
Study Area	2
Objectives	3
Data Collection - Methods	4
Fuel Inventory	4
Stand Information	4
Fire History	6
Stand Selection	8
Disease	8
Literature Review	11
Fuel Quantification	12
Disease Effects	16
Insect Effects	16
Fire History	17
Data Analysis	21
Discussion	28
Literature Cited	29

LIST OF TABLES

		Page
1	Density plot size	5
A	Apparent fire years and number of stands attributed to each fire	18
B	Age-class distribution by 20 year increments for 71 lodgepole pine stands	20
C	Dependent variables selected for regression analysis	22
D	Independent variable occurrence in 6 best equations	25

LIST OF FIGURES

		Page
1	Fuel loading vs. stand age for 71 lodgepole pine stands	26
2	Fuel loading vs. DBH for 71 lodgepole pine stands	27

INTRODUCTION

Fire has been an influential factor in determining the composition of forest vegetation since the last glacial period. Measured amounts of charcoal and pollen from lake sediment in Minnesota have shown how fire has affected the composition of the forests of that area for more than 10,000 years (Wright 1969). Numerous fire history studies in the Rocky Mountains have further documented the occurrence of fire on the landscape (Clements 1910, Mason 1915, Flint 1929, Habeck 1970, 1972, 1973, Houston 1973, Arno 1976, Sneck 1977) and many have determined for local areas the compositional changes that have taken place due to fire. Just as fire affects the composition of the vegetation within the ecosystem, so does it affect the fuel complex (Habeck 1970, 1972, Brown 1973). The intensity of fire greatly affects the quantities of both ground and aerial fuels (Steele, Stark, and Norum 1974). Quantities of downed woody fuel are both created and reduced by wildfires of both high and low intensity. Wind, insects and disease further affect fuel quantities. The great variability in fire intensities and climatic conditions through one or more burning seasons results in fuel loadings which are highly variable.

Protection agencies have been concerned for many years about the relationship between fuels and protection capabilities. The slow rate of decomposition of fuels and effective fire suppression may contribute to abnormal fuel loads within many forested areas of the Northern Rocky Mountains. Fuel inventory procedures have been developed to assess fuel quantities in the field and assist in estimating fire potential (Brown 1974). Data from fuel inventories can tell us how much fuel is present on a given area at a single point in time. Knowing the quantities of fuel present aids land managers in planning management activities. However, fuel

conditions never remain static. Fire, insects, disease, natural mortality, litter fall, and man-caused factors can singly or collectively alter the quantities of fuels present on a site. Thus, inventory data taken today could be grossly inaccurate within a few years. To effectively manage our wildland resources it would be desirable to estimate fuel quantities at any point in the successional cycle of a forest stand. The time and expense of periodic inventories is a problem to the land manager operating with tight constraints on funds and personnel. An approach is needed that would minimize the amount of fuel inventory needed (Anderson 1975). This study attempted to develop predictive equations of fuel accumulations based on stand characteristics. This could greatly reduce the need for periodic field inventories.

Lodgepole poine (Pinus contorta Dougl.) was selected for study because it is an aggressive pioneer species that usually forms even-aged stands following the occurrence of high intensity wildfires. Downed woody fuels are often reduced to low levels as a result of wildfire in lodgepole pine, thus fuel accumulation may be less complicated in this species than in other timber types.

STUDY AREA

The study area chosen for the first field season was the Tolan Creek Drainage located on the Sula District of the Bitterroot National Forest, Ravalli County, Montana. The drainage encompasses approximately 9,000 acres of mountainous terrain ranging in elevation from a high of 8,185 feet on the Continental Divide to a low of approximately 4,600 feet near where Tolan Creek flows into the East Fork of the Bitterroot River.

A second field season was required in order to expand the data base

and locate stands in various age classes not present in Tolan Creek drainage. In the summer of 1976 the study area was expanded to include all lodgepole pine stands within the East Fork of the Bitterroot River drainage.

Trees present on the study area includes lodgepole pine, Douglas fir (Pseudotsuga menziesii (Mirb.) Franco), subalpine fir (Abies lasiocarpa (Hook.) Nutt.), spruce (Picea engelmannii Parry), Whitebark pine (Pinus albicaulis Englem.), and ponderosa pine (Pinus ponderosa Laws.).

The nearest official climatological station is about 2 miles from the mouth of Tolan Creek at an elevation of 4,400 feet. Data from this station for the period 1956 through 1974 show that total precipitation for the Sula area has averaged 15.5 inches per year. Average January temperature is 20.2 F and average July temperature is 61.0 F. Average annual snowfall near Saddle Mountain (elevation 8,482 feet) was 300 inches (for the period 1953-1967). Snow often remains on the study area until mid-June.

OBJECTIVES

This study was intiated in 1975 to determine the relationships between stand characteristics (density, height, crown length, crown width, d.b.h., basal area, clear bole length, and age) site characteristics, (habitat type, aspect, slope, elevation) and fuel loadings and depths (0-1/4 in., 1/4-1 in., 1-3 in., 3+ in sound and rotten fuel, duff depth, fuel depth, shrub height and percent cover, grasses, forbs and herb percent cover.)

An attempt was also made to determine the effect of past insect (Mountain Pine Beetle), and disease (Lodgepole Pine dwarfmistletoe) infestations on fuel loadings.

Historical fire occurrence was documented within each stand studied in order to determine what effect historical fire had on fuel loadings as related to stand age.

DATA COLLECTION

Data collected for this study can be divided into four basic groups.

First, fuel inventory data was collected to describe the downed woody fuels, brush, duff, grasses, herbs, forbs and seedlings. Second, stand information data was collected and ultimately used as independent variables in the subsequent analysis. Third, insect and disease conditions within each stand were investigated. And, fourth, fire history was documented for each stand studied.

FUEL INVENTORY

Standard procedures have been developed at the Northern Forest Fire Laboratory for quantifying downed woody fuels. Procedures described in Dr. J. K. Brown's Handbook for Inventorying Downed Woody Fuels Material, 1974 were used.

STAND INFORMATION

Two methods for measuring density were used:

Crown Competition Factor (CCF). - - This method developed by Krajicek and others (1961) compared growing space available to a tree with that represented by a vertical projection of the average crown area of an open-grown tree of the same stem diameter. This comparison is made on a group basis. A CCF equation was developed for lodgepole pine by personnel of the Rocky Mountain, Intermountain, and Pacific Northwest Forest and Range Experiment Stations, (Alexander, Tackle, and Dahms 1967). This equation

was one method used to determine density for this study. The equation follows:

$$CCF = 1/A \left(0.01925 \sum_{i-1}^{k} N_i + 0.01676 \sum_{i-1}^{k} D_i N_i + 0.00365 \sum_{i=1}^{k} D_i^2 N_i\right)$$

where

CCF = Crown Competition Factor
A = area in acres
N = number of trees in each diameter class
D = d.b.h. class
K = number of d.b.h. classes

The following data is needed for CCF calculations (Alexander 1966):

1. To determine average height and age of the stand, select four or more dominant trees (site trees) and measure heights and ages. Average total age may be approximated from age at breast height by adding 9 years to the average age at breast height.
2. Establish density plot for each "site tree". This is a fixed-radius plot containing the "site tree". Plot sizes used depend on height of "site trees". Once a plot radius is chosen it is used for all sites studied within that particular stand.

Table 1. Sizes of density plots to use for different maximum heights of site trees

Maximum height of site trees	Plot radius	Plot size
Feet	Feet	Acre
75	52.67	0.2
75	37.25	.1
53	26.33	.05
37	18.67	.025
24	11.75	.01
17	8.33	.005
12	5.92	.0025

Once plot radius is determined, diameters at breast height of all trees on the density plot are measured and recorded by 1-inch size classes and live/dead status of each tree was recorded. From these data, the CCF and site index is determined.

Point Centered Quarter Method. - - In this method, described by Cottam and Curtis (1956), a series of points were chosen by pacing a fixed distance along a predetermined compass line. At each point, the space around that point was divided into quarters by placing the midpoint of a yardstick on the point chosen and oriented in the direction of the compass line. A second yardstick bisects the first at a 90° angle. Within each quarter, the tree nearest to the point was chosen and its distance from the point and its basal area was determined and recorded. From these data, trees per acre, basal area per acre, and average basal area per tree was computed. Twenty points per stand were used to collect density data.

ADDITIONAL TREE MEASUREMENTS

Each site tree and four dominant trees were chosen on each density plot and measured to determine the following information:

1. Total height
2. Live crown length
3. Live crown width (two measurements per tree taken at right angles)
4. d.b.h. (can be converted to basal area)
5. Clear bole length
6. Age - determined by increment bore

HABITAT TYPE

The habitat type or types within each stand selected for study were determined using "Forest Habitat Types of Montana" by R. D. Pfister and others (1974).

FIRE HISTORY

Fuel accumulation was based on time since the most recent fire that

affected the stand. Fires that have occurred subsequent to stand establishment will alter the fuel load. Each lodgepole pine stand was examined to determine if any fire activity had taken place that would alter the fuel load since the establishment of the stand. When fire scars were found on trees within a chosen stand, a small number of trees of small diameter were felled and a cross-section showing the scarring patterns was taken. In trees with large diameters, a wedge was removed from the most intact side of the catface so as to minimize damage to the tree. Any sections or wedges taken were identified by stand number. The location of each fire-scarred tree sampled was plotted on a 4-inch-to-the-mile map to assist in determining the coverage of the fire within the stand. Wedges and cross-sections were dried and sanded in the laboratory and analyzed (following the techniques of Stoakes and Smiley 1968). Time since fire was the same as stand age for all stands that revealed no fire disturbance. If fire scars which are highly time-correlated were found within a stand, time since fire may differ from stand age and "an adjusted stand-age" was used in the analysis. Fuel survival following fire will vary with intensity of the fire and other factors, but for purposes of this study fuel accumulation rates assumed "0" fuel at year "0". Increment cores were preserved intact, mounted in grooved mounts and surfaces were sanded. Although the cores were used primarily for stand aging purposes, they did aid in determining extent of fire boundaries. Since the cores were taken from known locations (from distance and azimuth data) they did prove useful in mapping fire boundaries.

As a further aid in locating stands, historical records were examined at the Sula District Ranger Station and the Bitterroot National Forest Supervisor's Office. Locations of past fires within the Tolan Creek

Drainage or nearby drainages were noted. These stands were located and used as needed.

A complete set of aerial photographs for the East Fork drainage were scanned for fire mosaic patterns and stand boundaries.

STAND SELECTION

Lodgepole pine stands chosen for study spanned the widest possible range of stand ages. In order to avoid gaps in data, five stands were selected for each 20-year time period. This was estimated to be the minimum number of stands in each 20-year time frame that was necessary for a statistically sound analysis (personal communication with M. A. Marsden, Mathematical Statistician, May 1975). Five stands per 20-year time frame were used primarily as a field guide. Subsequent analysis was not bound to this interval.

Based on examination of timber type maps of the Tolan Creek Drainage, it was clear that an insufficient number of stands were available within the Tolan Creek Drainage to meet data requirements. The Tolan Creek Drainage was considered the primary stand selection area. After all possible stands were measured within this drainage, additional stands were sought in adjacent areas of the East Fork of the Bitterroot River Drainage. A sufficient number of stands were found within the boundaries of the Sula District, Bitterroot National Forest, to fulfill the data requirements.

DISEASE

Lodgepole Pine Dwarfmistletoe (Arceuthobium Americanum). - - Dwarfmistletoe infections in lodgepole pine forests may affect the rate of downed woody fuel accumulation and the character of the fuel. In order to

investigate this possible effect, all trees within each density plot (discussed under CCF methodology) were examined and dwarfmistletoe presence was documented utilizing methods described by Graham (1964). The severity of infection in each tree was determined by dividing the live crown into two equal parts. Each half was rated as:

0 = no infection
1 = less than one-third of the branches infected
2 = more than one-third of the branches infected

Values from each half were added to give an overall rating for the tree. This was done for each tree on every density plot. Averages from these data were used as overall rating for each lodgepole pine stand. Five classes of dwarfmistletoe infection were used:

0 = dwarfmistletoe free
1 = lightly infected
2 = moderately infected
3 = heavily infected
4 = very heavily infected

If dwarfmistletoe infections were present in a stand, one infected tree per density plot was felled and two cross sections were removed and examined to determine age at onset of infection in each tree (Hawksworth 1954, Kimmey and Graham 1960).

Mountain Pine Beetle (Dendroctonus ponderosae). - - This bark beetle is credited with being responsible for extensive damage in lodgepole pine stands in portions of the Bitterroot Valley where severe mountain pine beetle epidemics occurred in the 1920's and 1930's (Evenden 1928, Gibson 1937, Evenden 1944, Evenden and Gibson 1940). In an attempt to quantify the downed woody fuel resulting from these epidemics, the following data was collected:

1. Following the standard fuel inventory procedures, intercepts encountered during the 3+ S and R survey were examined for presence of characteristic mountain pine beetle galleries. All intercepts to a maximum of ten intercepts were examined per inventory point. If more than ten intercepts occurred on any 20-foot transect, five intercepts were chosen at random for the first 10 feet of the transect, and five from the last 10 feet of the transect. Presence or absence of mountain pine beetle galleries was recorded for each fuel piece examined.
2. One cross-section per inventory point was removed from a 3+ sound fuel particle showing mountain pine beetle galleries. Utilizing techniques published by Stokes and Smiley (1968) from the Tree-Ring Research Laboratory in Tucson, Arizona, an attempt was made to cross date this particle with old-growth lodgepole pine from the area to determine year of death of beetle killed downfall. Existing literature on mountain pine beetle infestations in the Bitterroot Valley proved very helpful in this cross-dating effort (Evenden and Gibson 1940).
3. To document current infestations of mountain pine beetle for data stratification purposes, each site tree and the four trees discussed under additional tree measurements were examined for presence of red foliage, beetle entry holes, brood in cambium, boring dust, blue stain, evidence of pitchtubes, and woodpecker flaking (Safranyik 1971, Safranyik and others 1974). No current infestations were found within the allowable diameter of any density plot. Several small outbreaks were noted outside of study plot areas.

LITERATURE REVIEW

GENERAL

Fuels related work began as early as 1914 when Dubois published comparative rates of spread for grass, brush, and timber based on acres burned per hour. These ratings were based on a "large number of fire figures" for slopes up to 40 percent and wind up to 8 miles an hour. Sparhawk (1925) published graphs for the Western United States and the Lake States showing the relationships between the size of fire to time elapsed between discovery and attack. He lists a large number of factors and subfactors (including fuels) that influence the area that will burn once a fire is started. Mitchell (1929) discusses upland forest fuels of the Lake States region as they relate to fire hazard. Order of inflammability is given for the various types of fuel found in that area. Show and Kotok (1929) list nine different cover types for northern California and discuss how they relate to man's efforts to control fire. Hornby's (1935, 1936) fuel type concept has been extensively used for over 35 years on an operational scale. This system classified or rated fuels according to potential rate of spread and resistance to control that could be expected from a fire occurring after a month of continuous midsummer drought. This method eliminated the detailed inventory step as superfluous on the assumption that men experienced in behavior of small fires could draw conclusions more accurately by looking at fuels rather than while looking at descriptions of them. Thus, no quantitative measurements were taken by Hornby's fuel mappers.

Matthews (1937) estimated degree of shading and forest cover in six fuel zones in an attempt to rate fuels according to factors governing fire behavior. The fuel examiner also estimated rate of spread and resistance

to control by a method similar to Hornby's. Fons (1946) conducted experiments with model fires in beds of homogeneous fuel particles to determine fundamental laws governing the rate of spread in forest-type fuels. Equations were derived for rate of fire spread which took into account the physical characteristics of the fuel particles, the arrangement of the bed, and atmospheric conditions.

Lyman, (1945) discusses Northern Rocky Mountain fuel types in which fuel reduction would be justifiable and discusses principles which are necessary as a guide in determining where, why, when, and how fuels should be reduced. In 1972, the Northern Region of the USDA Forest Service published Fuel Management Planning and Treatment Guides (USDA Forest Service 1972a, b) which discuss specific methods and procedures for fuel management planning and treatment and prescribed burning. A handbook published by Brown (1974) presents procedures for inventorying downed woody material created by man's activities or by natural processes. This method utilizes the planar intersect technique described by Brown (1971) and Van Wagner (1968).

Dichotomous keys have been published by Fahnestock for rate of spread and crowning potential in order to establish the framework for a permanent, universal fuel appraisal system (Fahnestock 1970). Anderson (1974) also dealt with this subject by defining elements which should be considered while appraising forest fuels and by presenting a conceptual approach for quantifying fuel appraisal that can assist land managers responsible for wildland resources.

FUEL QUANTIFICATION

Few studies have dealt with the forest fuel complex in lodgepole pine

forests. Most previous fuel work reported deals with individual forest fuel components in terms of weight and size of fuels.

Brown (1973) examined the many relationships between fire and lodgepole pine forests in British Columbia and Alberta, Canada. Muraro was unable to determine useful relationships between surface fuels and stand characteristics. He cited several conditions which prevented him from developing stand-fuel relationships which had sufficient confidence for specific fire control application. These conditions as listed by Muraro are:

1. The availability and location of fuel components within the fuel complex presented by the original stand.
2. Depth and moisture content of the organic layer under the original stand.
3. Spread and residence characteristics of the destroying fire.
4. The availability of viable and seed after the original stand is destroyed.
5. Subsequent fire history that altered the newly established stand.
6. Productivity of the site.

Simple and multiple regressions were used to analyze data collected in lodgepole pine stands ranging from 19 to 200 years in age. Correlation coefficients of 0.4 and lower were common using stand parameters as independent variables.

Kiil (1967) studied the fuel complex in 70-year old lodgepole pine stands of different densities in Alberta, Canada. He investigated how stand density affects the weight and size distribution of aerial and ground fuels on his study site. He identified the stand parameters that could be used as predictors of fuel weight and size distribution. Kiil found basal area a useful field measurement for estimating weight and size distribution

of some fuel components; however, no correlation between stand density and weight of all ground surfaces was found.

McArthur (1962) showed a relationship between surface fuel quantity, number of years since last burn, and canopy cover for eucalypt forests in Australia. His predicted quantity of surface fuel is adjusted for percentage cover of shrubs. If years since last burn is unknown, fuel quantity can be estimated from a graph showing the relationship between depth of fuel bed and surface fuel quantity again with an adjustment for percentage shrub cover. Additional graphs are presented which deal with the effect of rainfall in reducing the amount of fuel available for combustion, wind-speed differences between open and forested areas, moisture content of surface eucalypt litter as related to air temperature, and relative humidity, rate of spread, slope, flame height, and scorch height. Some 400 experimental fires have been studied as well as a number of large wildfires.

Lamois (1958) and Dieterich (1963) investigated the range of fuel weights in red pine plantations in the Lake States. The variation in fuel weights due to spacing, age, and quality of the plantation site were key factors in their study.

Several studies have reported relationships between crown weight, d.b.h., crown length, crown width, and total tree height (Storey, Fons, and Sauer 1955, Fahnestock 1960, Kittredge 1944, Brown 1963, 1965).

Kiil (1971) estimated weights of tree components of lodgepole pine from large scale aerial photographs and compared these data with actual measurements taken on the ground. No significant differences were noted between the two methods.

Fahnestock (no date), in a preliminary report of his doctoral dissertation, describes forest fire fuels in the Pasayten River Drainage of north central Washington. This case study presents a hypothesis of fuel succession and then compares field measurements with the hypothesized model. Fahnestock reports that fuel succession after fire follows a predictable rhythm, and lists the following implications for fire management:

1. Sixty-odd years of protection cannot have caused a dangerous fuel buildup.
2. The long-term effects of protection cannot be gauged yet.
3. There is no immediate need for fuel reduction.
4. Prescribed burning as a fuel-reduction measure would be counter productive.

Crosby (1961) studied the annual accumulation of new litter in shortleaf pine stands in southeast Missouri and found stand basal area significantly related to the weight of litter and duff.

Nondestructive techniques used by Buckman (1966) in developing a volume equation for hazel in Minnesota could be applied to other studies interested in productivity and fuel relationships of shrubs. Dry weight of tree components and total biomass in conifer stands were estimated by Baskerville (1965). His most useful equation for estimating ovendry weight of tree components listed d.b.h. as the key independent variable. Rogerson (1964) found d.b.h. and basal area key factors in determining the weight of foliage on loblolly pine trees in Mississippi.

Norum (1975) investigated fire intensity and fuel reduction relationships for 22 experimental fires in standing timber in western Montana. Predictive equations for various fuel size classes were developed based on prefire and postfire fuel inventories, fuel moisture content measurement, slope, and windspeed.

DISEASE EFFECTS

Five thousand seven hundred sixteen trees were examined on the 71 plots selected for final analysis. Of this total, 1140 were found to have Dwarfmistletoe infection of varying degrees. Dwarfmistletoe infestations were found in stands as young as 44 years old, and in stands as old as 319 years. Only 13 stands had more than 50% of the trees within the density plot infected. Thirteen stands had from 1 to 46% of trees infected and 44 stands had no Dwarfmistletoe present.

The small number of stands with more than 50% of trees infected precluded any meaningful analysis to investigate possible fuel loading effects due to Dwarfmistletoe. Fuel loading and age structures appeared normally distributed with stands with no mistletoe present or with only small percentages (L.T.50%) of trees infected.

INSECT EFFECTS

Throughout the 48 stands investigated during the first field season, Mountain Pine Beetle activity was observed and cross-sections of 3+S fuels were collected. All samples taken were sanded and examined in the laboratory. Nearly all samples required the use of a magnifying instrument in order to accurately count the tree-rings. The purpose in counting tree-rings was to determine both the age of the tree at death and the total age. Total age was to be determined by cross-correlating tree-ring series with samples taken from living trees from the same vicinity as the samples. It was soon apparent that the complacent nature of the ring-series would make this correlation impossible. Slow growth rates and lack of sensitivity in the tree-rings were contributing factors. No dateable tree ring series were discernable. Thus, the attempt to determine the impact of the

Mountain Pine Beetle on fuel loading failed. Based on these findings following the first field season, no Mountain Pine Beetle fuel samples were taken the second field season.

FIRE HISTORY

Historical fire occurrence for 3 study areas on the Bitterroot National Forest, Montana was documented by Arno (1976). His results show that fire was historically a major force in influencing stand development within his study areas. Fifty of the 71 Lodgepole Pine stands investigated during this study were within the boundaries of Arno's Tolan Creek study area. Close comparison of age-class data with Arno's Master Fire Chronology was thus possible. Table A presents data from this comparison. Lodgepole stands studied within the Tolan Creek drainage could be easily related to specific historical fires which occurred in Tolan Creek from 2-15 years prior to establishment of the oldest trees sampled in each stand. Age-class data verify Arno's findings that in the years 1847, 1811 and 1785, fires burned throughout the Tolan Creek drainage. Thirty-eight stands studied can be attributed to fires occurring in those 3 years.

Twenty-one Lodgepole Pine stands studied were outside of the Tolan Creek drainage. No historical fire occurrence data is available for these areas (all were within the East Fork Bitterroot Drainage). Years of establishment of the dominant trees within these stands are denoted with an asterisk in Table A.

Twelve stands studied showed evidence of fire within the stand subsequent to stand establishment. These fires appear to have been low-intensity creeping ground fires as evidenced by sporadic scarring patterns throughout the stand. Multiple age-classes resulted in these stands. Multiple tree scars were evident on certain trees while nearby trees were

TABLE A--Apparent Fire Years and number of stands attributed to each fire. East Fork of the Bitterroot River drainage. Bitterroot National Forest, Montana

FIRE YEAR	FIRE YEAR
1950*	1889*
1947*	1883*
1945*	1874*
1934*	1871-1
1926-2*	1870*
1917-2*	1863-1
1913-2*	1847-8
1909*	1821-3
1908-1	1811-7
1906*	1803-1
1905*	1785-23
1903*	1757-1
1902*	1632-2
1899-2*	1595-1
1892-1	

*Denotes year of establishment of dominant trees in each stand

not scarred. To speculate on the degree of fuel reduction within these stands due to these subsequent low-intensity fires would be guesswork at best. Thus, "adjusted age-classes" were not used as originally planned.

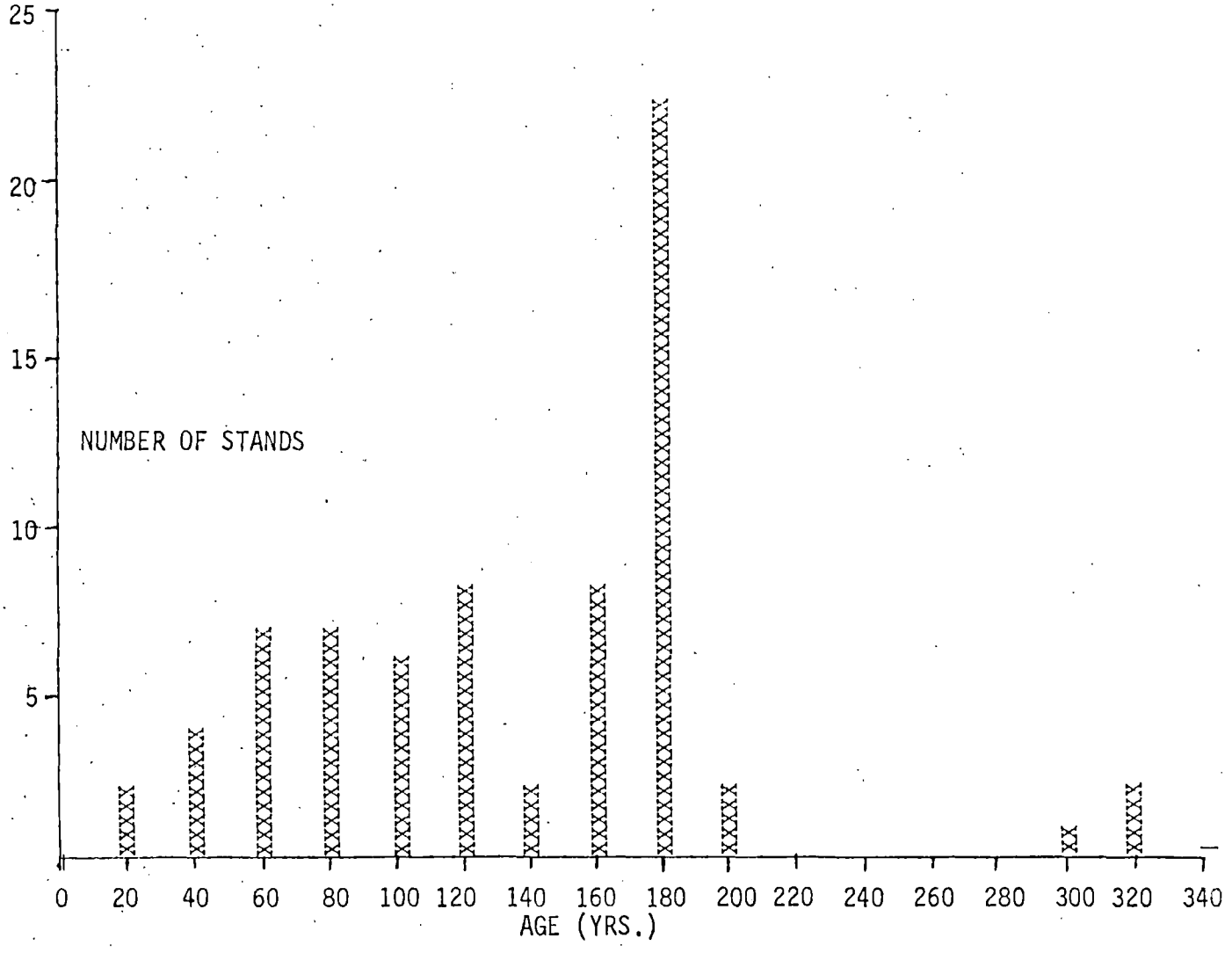
Eighty-three percent of all Lodgepole Pine stands showed no evidence of fire occurrence subsequent to stand establishment. Increment cores were taken from dominant trees within every stand. Counts from these cores showed that nearly all stands had even-aged structures. Differences in the ages of dominant trees with each stand normally varied from 2-15 years.

Table B shows the age-class distribution by 20 year increments for the 71 stands used for the final analysis. The largest age-class present in the East Fork drainage occurred in the 180-200 year age class. Nearly all of these stands were the result of the fire or fires which occurred in the year of 1785.

Only 3 high elevation ridge top stands were located which were older than 220 years. These 300+ year old stands, due to their location, probably escaped the effects of historical fires in the Tolan Creek drainage.

Most age classes were represented by a minimum of 5 stands per 20 year age class. Only 2 stands could be located which fell in the 130-150 year age class.

TABLE B--Age-class distribution by 20 year increments for 71 Lodgepole Pine stands.



DATA ANALYSIS

Results of the data analysis are presented below. Fuel description variables were regressed using multiple linear regression for 23 independent variables (Xi) and 6 dependent variables (Yi).

All variables used to describe stand, site, and fuel characteristics are listed in Table C. Several thousand equations were generated using from 1 to 4 (maximum) independent variables. All possible combinations of independent variables were regressed against each dependent variable. Equations accounting for the most variation for each dependent variable are listed. Fuel loading was analyzed by individual size classes and then by groups of size classes. Dependent variable Y(6) included all size classes, sound and rotten fuel, and duff weight. The REX program was used in each case to screen all combinations of independent variables listed in Table C, up to a maximum of 4 independent variables. Equations of best fit were selected from the thousands of equations generated. The six equations which follow were the best for each dependent variable in terms of explaining the largest amount of variation for that variable.

For the 6 equations, which account for the largest amount of variation for each dependent variable, R^2 values range from .27 to .66 with Y6 (Grand total fuel loading), being the highest in terms of explained variation.

TABLE C--Dependent (fuel loadings and independent stand, site, fuel loadings and depths) variables selected for regression analysis.

DEPENDENT VARIABLES

Variable	
Y(1)	0-.25" size class fuel loading
Y(2)	.25-1" " " " "
Y(3)	0-1" " " " "
Y(4)	0-3" " " " "
Y(5)	TOTAL (0-3" + sound + rotten) fuel loading
Y(6)	GRAND TOTAL (0-3 + sound + rotten + duff weight) fuel loading

INDEPENDENT VARIABLES

X(1)	Stand Age
X(2)	Average tree height
X(3)	Average crown length
X(4)	Average crown width
X(5)	DBH
X(6)	Average clear bole length
X(7)	Crown competition factor
X(8)	Relative frequency
X(9)	Relative density
X(10)	Relative dominance
X(11)	Importance value
X(12)	Site index
X(13)	Elevation
X(14)	Duff depth
X(15)	Average dead fuel depth
X(16)	Average brush height
X(17)	Terrain slope
X(18) (Y1)	0-.25" size class fuel loading
X(19) (Y2)	.25-1 " " " "
X(20) (Y3)	0-1" " " " "
X(21) (Y4)	0-3" " " " "
X(22) (Y5)	0-3" (+sound + rotten) size class fuel loading
X(23) (Y6)	Grand total fuel loading (0-3" + sound + rotten + duff weight)

Fuel loading of 0-¼ inch (0 to .635 cm.) age class woody fuels (Y1)

$Y = 1466.7 + .909\ (X7) + 10.5\ (X8) - 11.1\ (X9) - .166\ (X13)$ where:

Y = Fuel loading in 0-¼ inch (0 to .635 cm.) age class woody fuels
X7 = Crown competition factor
X8 = Relative frequency
X9 = Relative density
X13 = Elevation

$R^2 = .35$ F = 8.9 significant at .001 level
Standard error of the estimation = 248.4

Fuel loading of ¼-1 inch (.635 cm. to 2.54 cm.) size class woody fuels (Y2)

$Y = 4097.8 - 104.9\ (X3) - 39.9(X10) + 58.4(X12) + 253.3(X15)$ where:

Y = Fuel loading in ¼-1 inch (.635 cm. to 2.54 cm.) size class woody fuels
X3 = Average crown length
X10 = Relative dominance
X12 = Site index
X15 = Average dead fuel depth

$R^2 = .34$ F - 8.4 significant at .001 level
Standard error of the estimation = 1801.7

Fuel loading of 0-1 inch (0 to 2.54 cm.) size class woody fuels (Y3)

$Y = 4398.1 - 111.9(X3) - 40.7(X10) + 63.6(X12) + 256.9(X15)$ where:

Y = Fuel loading in 0-1 inch (0 to 2.54 cm.) size class woody fuels
X3 = Average crown length
X10 = Relative dominance
X12 = Site index
X15 = Average dead fuel depth

$R^2 = .33$ F = 8.1 significant at .001 level
Standard error of the estimation = 1930.5

Fuel loading of 0-3 inch (0 to 7.62 cm.) size class woody fuels (Y4)

$Y = 56208.1 - 259.7(Y3) + 184.8(X6) - 35.4(X11) - 5.2(X13)$ where:

Y = Fuel loading of 0-3 inch (0 to 7.62 cm.) size class woody fuels
X3 = Average crown length

X6 = Average clear bole length
X11 = Importance value
X13 = Elevation

R^2 = .27 F = 11.2 significant at .001 level
Standard error of the estimation = 7174.6

Total fuel loading (0-3 inch plus sound and rotten)(Y5)

Y = 203949.4 - 264.4(X7) + 1042.8(X12) + 35.3(X13) + 6053.9(X15) where:

Y = Total fuel loading (0-3 inch size class plus sound and rotten fuels)
X7 = Crown competition factor
X12 = Site index
X13 = Elevation
X15 = Average dead fuel depth

R^2 = .41 F = 11.2 significant at .001 level
Standard error of the estimation = 45174.1

Grand total fuel loading (0-3 inch size class (0 to 7.62 cm.) plus sound and rotten fuels and duff weight) (Y6)

Y = 112304.4 - 221.5(X7) + 28.1(X13) + 38577.2(X14) + 5146.2(X15) where:

Y = Grand total fuel loading (0-3 inch size class (0 to 7.62 cm.) plus sound and rotten fuels and duff weight)
X7 = Crown competition factor
X13 = Elevation
X14 = Duff depth
X15 = Average dead fuel depth

R^2 = .66 F = 3.1 significant at .001 level
Standard error of the estimation = 47656.3

Table D shows the frequency of occurrence of each variable which occurred in the final 6 equations.

TABLE D: Independent variable occurrence in 6 best equations.

Dependent Variable	Independent Variables										
	X3	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
Y1			X	X	X				X		
Y2	X					X		X			X
Y3	X					X		X			X
Y4	X	X					X		X		
Y5			X					X	X		X
Y6			X						X	X	X
TOTAL	3	1	3	1	1	2	1	3	4	1	4

Elevation (X13), average dead fuel depth (X15), average crown length (X3), crown competition factor (X7) and site index were the strongest independent variables in the final equations. These 5 variables (X3, X7, X12, X13, X15) accounted for 17 of the 24 resulting variables.

Stand age (X1) and DBH (X5), surprisingly, did not occur in a single resulting equation. Figures 1 and 2 show why. A plot of the data for these 2 variables with Y6 (Grand total fuel loading) shows a scattered, non-correlated pattern. Many other scatter diagrams of independent variables with dependent variables resulted in similar patterns.

Figure 1 = Fuel loading vs. stand age for 71 Lodgepole Pine stands. East Fork Bitterroot drainage, Montana

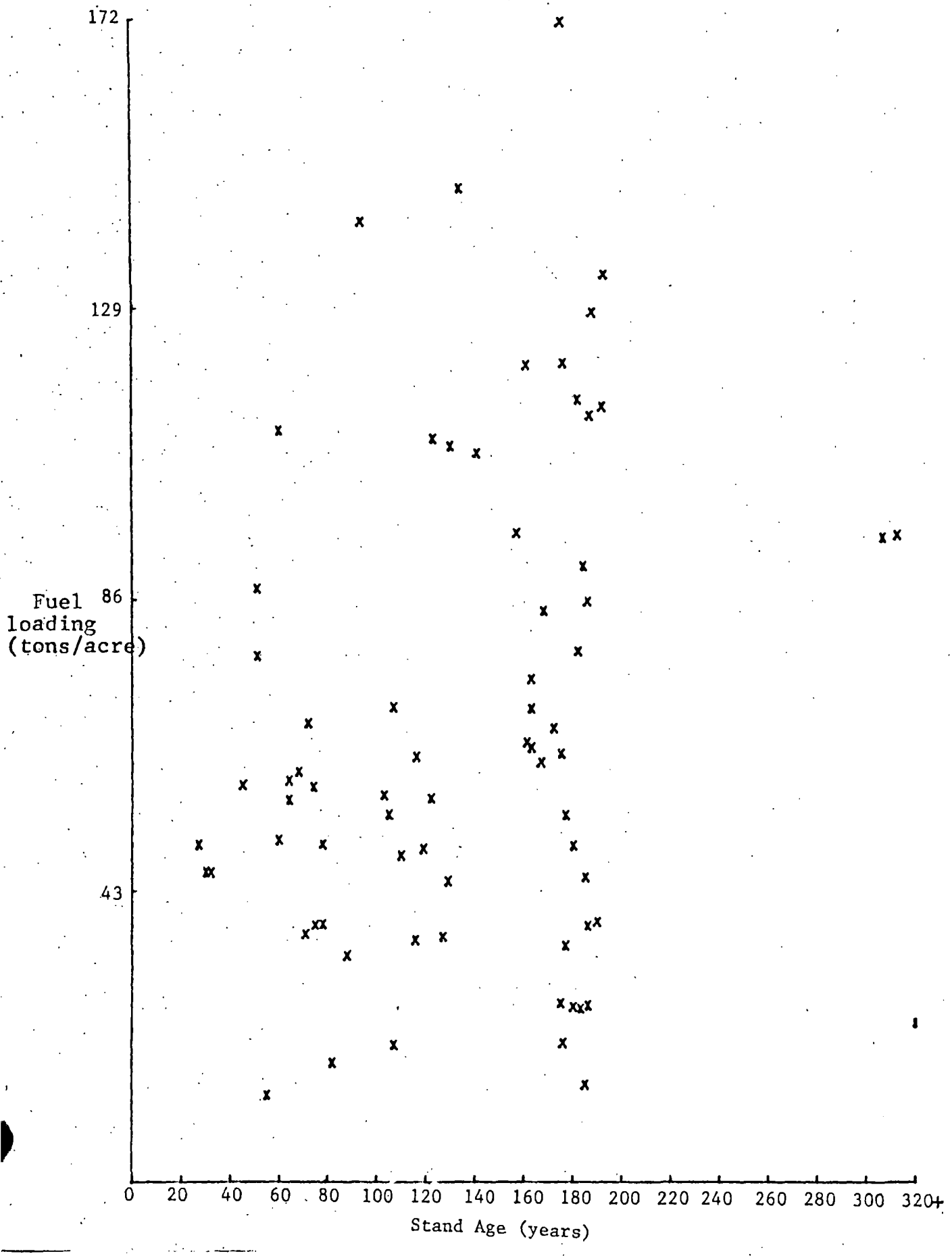
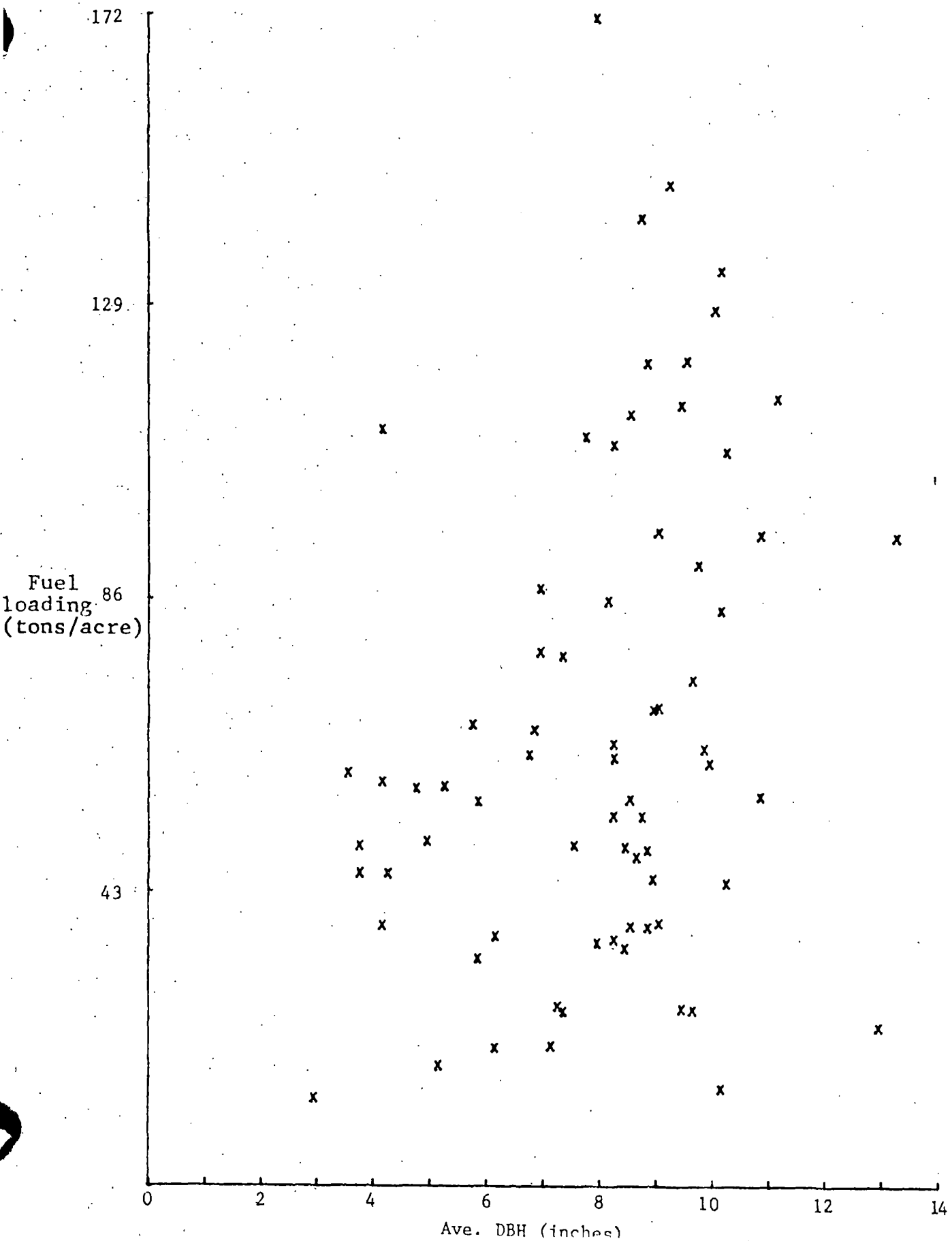


Figure 2 = Fuel loading vs. average DBH for 71 Lodgepole Pine stands. East Fork Bitterroot River drainage, Montana



DISCUSSION

The primary objective of this study was to test the hypothesis that fuel loading is related to site characteristics and stand characteristics. Results indicate that no simple relationship exists for the variables investigated. Equations which account for less than 66% of the fuel complex lack sufficient confidence for application by fuel managers.

The inability to document complex stand history interactions may preclude predicting fuel loadings based on stand and site characteristics. Results of similar studies in Lodgepole Pine by Alexander (1978) in Colorado, Muraro (1971) in British Columbia, and Brown's current work show similar, poor relationships.

A number of key factors may be responsible for the results obtained. Some of these factors are:

1. The inability to quantify residual fuels resulting from historical fires.
2. The inability to quantify the effects of the mountain pine beetle on the fuel complex.
3. The inability to quantify the effect of Dwarfmistletoe on the fuel complex.
4. The variable intensity and spread of historical fires which altered existing stands of Lodgepole Pine.

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